FINAL

TECHNICAL MEMORANDUM

To: Doug Thomas,
Board of Water and Soil Resources

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File 4875-027

Subject: Prioritizing, Measuring and Targeting Application (PTMApp)
Categorization of Best Management Practices and Conservation Practices for Estimating Pollutant Removal Effectiveness

Date: December 3, 2014

Project: 4875-027

BACKGROUND

The International Water Institute (IWI) on behalf of the Red River Watershed Management Board, received a 2014 Clean Water Fund Accelerated Implementation Grant from the Board of Water and Soil Resources (BWSR) for the development of the Prioritization, Targeting and Measuring Water Quality Improvement Application (PTMApp) (referred to as "the Project"). The stated purpose of the Project is to leverage the geospatial data created by the IWI during the completion of their 2012 Accelerated Implementation Grant (AIG) by developing, testing and deploying an operational application for prioritizing subwatersheds and targeting fields for the implementation of nonpoint source Best Management Practices (BMPs) and Conservation Practices (CPs) based on water quality. The 2012 AIG developed methods to estimate the delivery of total nitrogen, total phosphorus, and sediment to downstream water resources and created enhanced GIS water quality products for the Red River of the North Basin. These data and in general the methods from the 2012 AIG grant will be adapted for the development of PTMApp. The PTMApp is also being developed, in part, to "measure" the effectives of BMPs and CPs in reducing nutrient and sediment loads. Therefore, additional tools are being developed to provide products identifying the potential locations for BMPs and CPs on the landscape, to estimate the pollutant reduction effectiveness and to provide a means of estimating cost for implementation.

This Technical Memorandum (TM) is one of several envisioned to describe development issues and proposed direction to BWSR. A companion TM titled "Prioritizing, Measuring and Targeting Application (PTMApp) Categorization of Best Management Practices and Conservation Practices for Estimating Pollutant Removal Effectiveness" (October 9, 2014) describes the proposed BMPs and CPs to be included in the application. These TMs serve as a communication tool to discuss, resolve and obtain concurrence with BWSR staff and others about application development. The purpose of this TM is to describe the technical methods proposed to compute the pollutant reduction benefits (i.e., BMP and CP effectiveness) within the PTMApp. Once the pollutant reduction benefits are estimated, their effectiveness will be used to “measure” progress toward achieving water quality goals.

PROPOSED METHODS FOR ESTIMATING PRACTICE COST-EFFECTIVENESS

One of the most challenging parts of “measuring” water quality improvements is estimating the reduction in total nitrogen (TN), total phosphorus (TP), and sediment resulting from implementing agricultural BMPs and CPs on the landscape. Some of the reasons that estimating the pollutant reduction benefits of agricultural BMPs and CPs is challenging include:

- The dependence upon specific design factors related to the BMP or CP;
- Effectiveness is a function of the location of the BMP or CP on the landscape, relative to the particular waterbody it is intended to protect or restore;
- Highly variable in-field monitoring results, caused in part because of the changing environmental conditions (e.g., amount of runoff); and
- Challenges associated with the ability to extrapolate monitoring data from one setting to another.

Because of these challenges, the pollutant reduction benefits of agricultural nonpoint source BMPs and CPs is often assumed as a fixed percentage of the load received and estimated at the BMP or CP location. These methods are inadequate for measuring progress toward achieving water quality goals at the actual waterbody for which a protection or restoration strategy is being developed.

The IWI and HEI are proposing methods for seven categories of CPs and BMPs, where the categories generally reflect the bio-physical processes for removing pollutants. The categories are:

1. Storage;
2. Filtration;
3. Bio-Filtration;
4. Infiltration;
5. Protection;
6. Source reduction; and
7. User Defined Practice.

The companion TM titled “Prioritizing, Measuring and Targeting Application (PTMApp) Categorization of Best Management Practices and Conservation Practices for Estimating Pollutant Removal Effectiveness” (October 22, 2014) identifies the specific BMPs and CPs within each category.

This section of the TM provides the theoretical basis for methods for estimating BMP and CP load reductions and measuring water quality improvement for a proposed implementation strategy as part of PTMApp development. The proposed methods include a means for providing planning level estimates BMP and CP construction cost. The remainder of the TM uses data developed through the IWI during the completion of their 2012 Accelerated Implementation Grant where techniques were developed to estimate the delivery of TN, TP, water, and sediment to resources of concern (i.e., a lake or stream segment). These techniques were developed using airborne light detection and ranging (LiDAR) elevation data and hydrologically conditioned digital elevation models (DEM) that conform to HEI standards (**Appendix A**). Based on initial testing the methods are also transferable to other data sets that have received sufficient hydrologic conditioning (e.g. National Hydrography Dataset (NHD) Plus).

It is our understanding that BWSR envisions prioritizing, targeting, and measuring to occur at a planning level (e.g. One Watershed, One Plan development) and tailoring of plans to occur at the local level after initial plan development. This TM describes methods for measurement techniques that can be used in the planning and tailoring phases for inclusion in the overall PTMApp development. The remainder of the TM provides background on theory applied in other projects and developed here for measuring water quality improvements from BMP and CP implementation and provides an example of outputs that could be generated as part of the One Watershed, One Plan planning process.

Estimating the load reductions resulting from BMP and CP implementation has been the focus of numerous efforts. The results from many of the studies investigating reductions in water quality constituents by BMP and CP implementation in agricultural settings have been summarized for Minnesota in an Ag BMP database (http://agbmp.houstoneng.net/). Constituent reductions from BMPs are generally assessed by modeling, empirical studies, or a combination of both. For example, the modeling measurement technique used in STEPL is based upon the Universal Soil Loss Equation (USLE), sediment delivery ratio (SDR), and literature values of TN and TP associated with eroded sediment (Tetra Tech. Inc., 2011). The STEPL user is prompted through a series of Microsoft Excel Spreadsheets to input data about the watershed, agricultural management practices, current BMPs, and USLE parameters. The user is then prompted again to input how the management system will be changed. The USLE and SDR are calculated for both scenarios to measure water quality improvements based upon land management changes. For structural BMPs, an assumed empirical constituent reduction efficiency is used. Similar spreadsheet calculators are being employed in Minnesota (see BWSR, 2013). However, these calculators are typically not designed to estimate BMP constituent reductions at a priority resource, but rather only estimate water quality improvements at the BMP.

Many models have been developed that include routines and options for estimating constituent reductions from BMPs in agricultural (e.g. Soil and Water Assessment Tool (SWAT) and Hydrologic Simulation Program-Fortran (HSPF)) and urban (e.g. P8 and XPSMM) landscapes. Typically constituent treatment is modeled within these software as a function of hydrology and/or hydraulics, with reductions in constituents often following some form of a decay function based upon the hydraulic residence time of a given constituent within a BMP (Elliot and Trowsdale, 2007). These decay functions can be based upon settling theory, 1st order decay, or 2nd order decay. In other words, the longer the water and constituents are treated the more they are reduced. Unfortunately, most existing software requires a technical expert to manipulate the modeling software to measure water quality improvements from BMP implementation and generally only “measure” reductions at the BMP, rather than at the priority resource.

CALCULATING REDUCTION RATIOS

A key step in “measuring” the impacts of BMPs for our proposed methods is estimating the volume of runoff that can be treated by a BMP (treatment potential) resulting from different precipitation events (delivery potential). IWI and HEI intended to use 2-year, 24-hour and 10-year, 24-hour precipitation as the standard precipitation events[1] in PTMApp development, as most BMPs are designed for treatment within this range of precipitation events. Our expectation is that the mass reductions estimated using the 2-year, 24-hour precipitation event will approximate annual average values (since it is a 50% chance precipitation event). Users of the PTMApp will be expected to assign precipitation depths corresponding to these storm events. It is suggested that these depths be based upon Atlas 14. The remainder of this section describes how reduction ratios will be calculated for each treatment group within PTMApp.

The “current” methods used to estimate BMP and CP effectiveness is to assign an assumed value. This approach fails to acknowledge that the effectiveness of BMPs and CPs in reducing load is based typically on either how the volume of water they receive (e.g., storage) or how rapidly water moves across the surface (e.g., filter strips). Conceptually, the recommended approach provides a continuous mathematical function between lower and upper percent reduction values (obtained from the literature), to estimate the reduction in load received by the BMP, based upon either the volume of water which can be treated or the rate by which water moves through the BMP (see **Table 1**).

Within PTMApp, the percent reduction of a water quality constituent will be based upon a reduction ratio and the empirical statistical distribution of BMP effectiveness within the treatment category (**Table 1**). For instance, the reduction ratio for Storage BMPS (e.g. wetlands, sediment control basins) will be calculated as the ratio of the volume of water delivered (Delivery potential) to the BMP under 2-year, 24-hour and 10-year, 24-hour precipitation events to the volume of water held by the storage BMP (Treatment potential). The proposed reduction ratios for each treatment group are shown in **Table 1**. BMPs and CPs will be placed in treatment groups based on the process by which water is treated (e.g., settling). This is necessary because of the large number of equations which would need to be developed for each type of BMP and CP if they were not placed into treatment groups and the general lack of data relative to effectiveness.

Table 1. Methods for estimating the reduction ratio for BMP and CP treatment groups.

	Storage	Filtration	Bio-Filtration	Infiltration	Protection	Source Reduction	User Defined
Reduction Ratio (*r*)	Treatment Volume / Runoff Volume Delivered	Velocity Design Standard / Velocity During Peak Discharge	Velocity Design Standard / Velocity During Peak Discharge	BMP Abstraction Volume / Volume Delivered	Modified RUSLE Parameters	Actual reduction in mass	User selects method (from those to left) or enters percentage

STORAGE

Storage BMPs generally provide treatment through sedimentation processes. The effectiveness of sedimentation processes are therefore related to the volume of dead storage (i.e., water stored within a

[1] Water quality BMPs and CPs are generally designed for more frequent storm events, rather than less frequent events like the 100-year return period storm as is typical for flood control projects.

permanent pool) and the volume of water delivered to the BMP. The IWI and HEI intend to calculate the reduction ratio of storage BMPs and CPs based upon the treatment volume of the practice (treatment potential) derived from topographical data and the total volume of water delivered to the practice (delivery potential) under 2-year, 24-hour and 10-year, 24-hour precipitation events. The volume of water delivered to a storage BMP will be calculated using the Curve Number (CN) method.

FILTRATION

Filtration practices generally provide treatment by allowing water to infiltrate and by slowing the velocity of water to allow for sedimentation processes to occur. The effectiveness of filtration BMPs are therefore a function of the velocity design standard and the velocity of runoff delivered across the surface of the BMP. Filtration practices are typically designed to treat a maximum velocity of 0.06 ft. sec-1. The IWI and HEI intend to use 0.05 ft. sec-1 as the treatment potential of filtration BMPs and CPs. This treatment potential velocity was calculated using stoke's law, assuming a 50 foot wide filtration practice that results in the silt and sand fractions of sediment being retained within the BMP. The velocity resulting from the peak rate of runoff (delivery potential) will then be calculated using the CN method and unit hydrograph theory to determine peak discharge for the 2-year, 24-hour and 10-year, 24-hour precipitation events. The reduction ratio will be reduced if the velocity exceeds 1.5 ft. sec-1.

BIO-FILTRATION

Bio-filtration practices generally provide treatment by slowing the velocity of water to allow for sedimentation processes and biological processes to occur. The reduction ratio for bio-filtration BMPs will be calculated using the same method as Filtration practices. IWI and HEI intended to use 0.06 ft. sec-1 as the treatment potential of bio-filtration BMPs. The velocity during peak discharge (delivery potential) will then be calculated using the CN method and unit hydrograph theory to determine peak discharge under 2-year, 24-hour and 10-year, 24-hour precipitation events. The effectiveness of bio-filtration practices will be differentiated from filtration practices based upon the empirical statistical distribution of observed treatment calculated using Equations 1 and 2 (below).

INFILTRATION

Infiltration practices generally provide treatment by allowing water to infiltration through the soil or other media. IWI and HEI intend to calculate the reduction ratio for infiltration BMPs based upon the volume abstracted (i.e. infiltrated) from runoff (treatment potential) and the volume of water delivered (delivery potential) to the BMP under 2-year, 24-hour and 10-year, 24-hour precipitation events. Both the abstraction volume and volume delivered to the BMP will be calculated using the CN method.

PROTECTION

Protection practices generally provide treatment by physically armoring the landscape in areas with high potential for erosion. This could include natural materials (e.g. tree, shrub, grass plantings) and/or manmade materials (e.g. rock filled gabion baskets). The IWI and HEI intend to estimate the reduction potential of protection BMPs and CPs based upon the amount of water quality constituents (TP, TN, Sediment) no longer being eroded from areas where protection BMPs can be placed on the landscape. The percent reduction in water quality constituents will be based upon the empirical statistical distribution of protection BMPs. For protection practices, reduction ratios will be set to 1 and their effectiveness will vary based upon empirical data.

SOURCE REDUCTION

Source reduction practices generally provide treatment by reducing the amount of water quality constituents (typically TP and TN) applied to the landscape. For example, nutrient management plans usually reduce the amount of fertilizer applied to agricultural areas. The IWI and HEI intended to measure the reduction potential of source reduction BMPs and CPs based upon their empirical statistical distribution for reducing TP and TN. This empirical distribution will be a function of published effectiveness values (e.g. AG BMP database, National BMP database) for the BMPs that are categorized into the source reduction treatment group.

USER DEFINED

With the state, national, and international focus on reducing non-point source pollution through the use of BMPs and CPs, accounting for every potential type of BMP and CP proves challenging. In order to allow greater flexibility in the BMPs captured within the PTMApp, IWI and HEI intend to allow users to define and input the effectiveness of User Defined practices. This will allow end user's to measure the effectiveness of current BMPs not captured within PTMApp and allow future BMPs to be incorporated into the application. The user will have the option of using assigned the treatment methods from any of the treatment groups, or inputting their own effectiveness value.

Estimating Constituent Removal

An empirical treatment decay function will then be used to transform the reduction ratio (*r*) into a percent reduction of a water quality constituent from the implementation of a BMP. The percent reduction (*R*) will be calculated as:

$$R = ar^k \quad \text{Equation [1]}$$

where *a* is a percent reduction in a water quality constituent taken from the empirical statistical distribution of the BMP treatment group, and *k* is a decay coefficient based upon the interquartile range of the empirical statistical distribution of the BMP treatment group. To account for potential uncertainty in the calculations, the *a* term will be modeled as the median (*Q2*), upper (*Q3)* and lower limit (*Q1)* of the inter quartile range, minimum and maximum of the empirical statistical distribution of the BMP treatment group. The decay coefficient, *k*, will be calculated as:

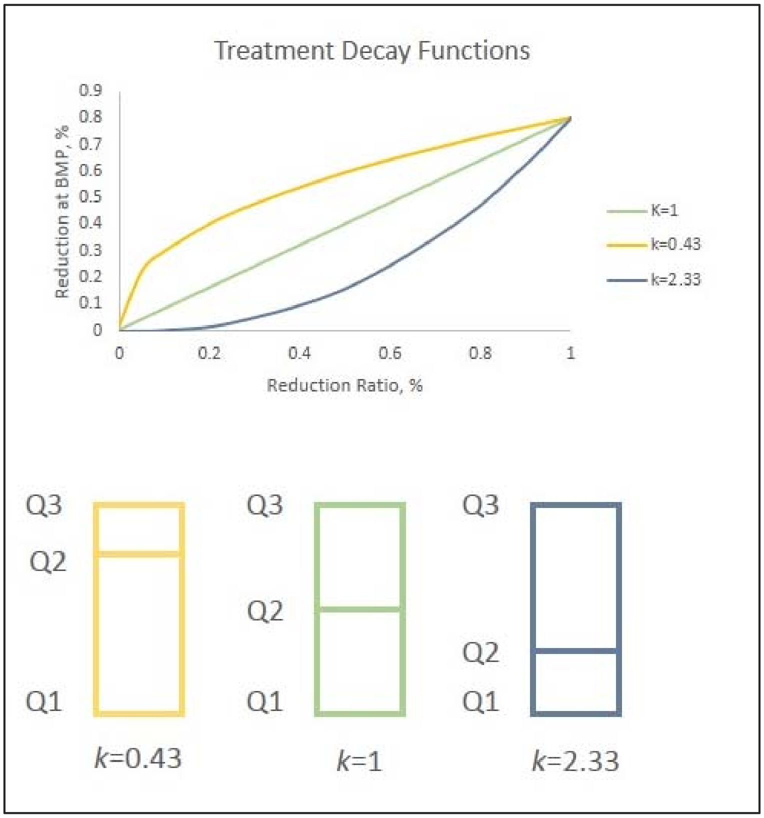
$$k = \frac{Q3 - Q2}{Q2 - Q1} \quad \text{Equation [2]}$$

where Q3 is third quartile (i.e. upper limit) of the empirical statistical distribution of the BMP and CP treatment group, Q2 is the second quartile (i.e. median) of the empirical statistical distribution of the BMP treatment group, and Q1 is the first quartile (i.e. lower limit) of the empirical statistical distribution of the BMP treatment group. The empirical statistical distribution will be established based upon the availability of research on a particular treatment group with priority going to studies conducted in Minnesota, then the Upper Midwest, and then the United States. Figure 1 is a graphical illustration of possible treatment decay function ranges assuming different values of k. The IWI and HEI intend to fit the decay coefficient values (k) for each treatment group based upon best available data.

Estimating Cost-Effectiveness and Optimum Treatment

The cost of implementing BMPs and CPs will be estimated on a per unit area or length basis. The IWI and HEI assumes that BWSR will be able to provide summary information on the average per unit area, length, volume basis for different types of BMPs. This cost information will be used to estimate the total cost of implementing BMPs on areas that are suitable for different treatment groups. The calculated costs will be paired with the estimates of constituent removal for each BMP treatment group. This information will be used to establish a cos-effectiveness and total potential constituent removal for each BMP treatment group. An efficiency frontiers will then be developed for each treatment group that identify the maximum reduction in a water quality constituent per dollar invested in a treatment group. The efficiency frontier will assume single practice implementation (i.e. won't account for BMP treatment trains). These efficiency frontiers will serve as a "measuring stick" for the cost-effectiveness of implementing individual best management practices.

Figure 1. Illustration of different treatment decay functions based on different decay coefficients (k).



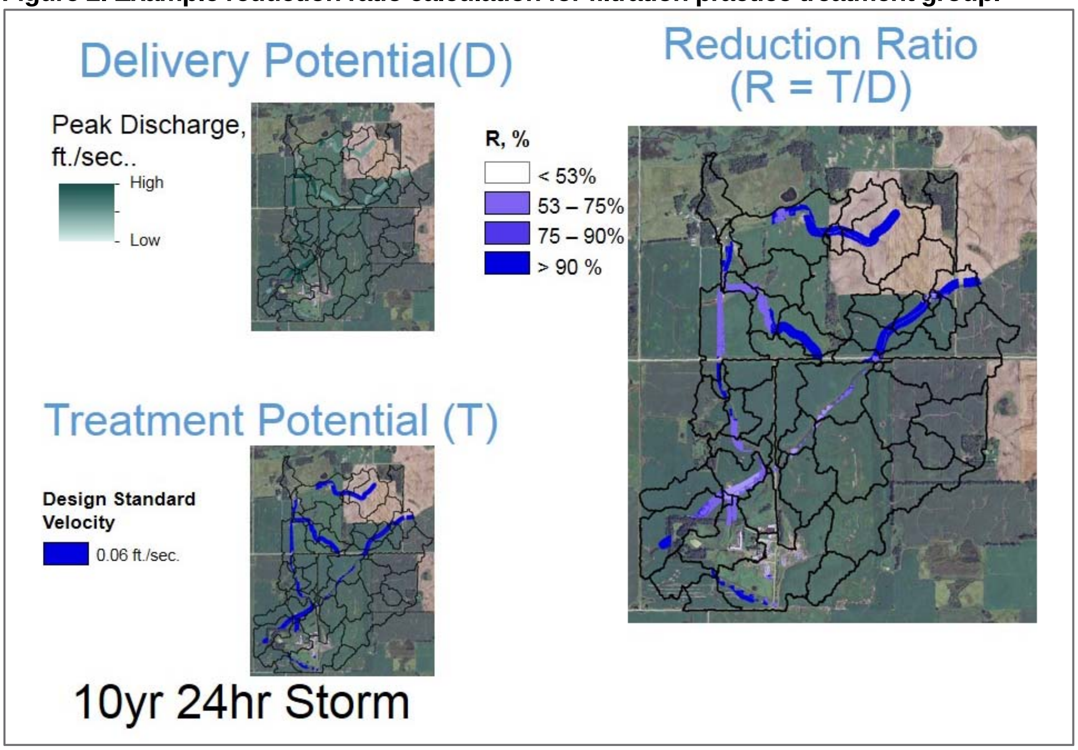
EXAMPLE OF "MEASURE" FOR FILTRATION TREATMENT GROUP

To clarify the methods described above and provide an example of the output data products that will be generated by the PTMApp an example cost-effectiveness analysis of filtration practices has been performed for a subwatershed in the Sand Hill River Watershed District (SHRWD). The SHRWD is used as the example because of past work completed in the District. This example is intended to obtain agreement on the types of "measure" methods and type of data products that the PTMApp will generate for use in the 1W1P planning process.

Calculating Reduction Ratios

The delivery potential and treatment potential for filtration practices were calculated for a subwatershed identified as a high priority for sediment reduction in the SHRWD (based on HSPF model results) using the runoff resulting from a 10-year 24-hour precipitation event (Figure 2). Peak discharge was calculated using the CN method and unit hydrograph theory. Peak Discharge was converted to a peak velocity and used as the delivery potential. A design standard of 0.06 ft. $sec.^{-1}$ was used for the treatment potential of filter strips. The treatment potential was divided by the delivery potential to estimate the reduction ratio. This example illustrates how reduction ratios will be calculated in the PTMApp. Once calculated, the reduction ratio can be transformed with a treatment decay function to “measure” reductions in TN, TP, sediment, and run off. The approach essentially assumes the reduction ratio is a function of how rapidly water moves across the surface of the filtration BMP.

Figure 2. Example reduction ratio calculation for filtration practice treatment group.



Estimating Constituent Removal

Table 2 shows an example of the empirical statistical distribution for sediment removal within the filtration treatment group and includes the resulting decay coefficient (*k*). The statistics are taken from the Minnesota Agricultural BMP database. As part of the PTMApp development, the IWI and HEI intend to develop similar tables for all water constituents (TN, TP, and sediment) for all treatment groups. Using *equation 1*, Figure 3 shows the resulting treatment decay results as a function of reduction ratios for filtration practices. By utilizing the range of observed treatment potential, the resulting treatment decay functions will account for uncertainty in BMP performance. Figure 4 shows the output transformation of the reduction ratio to percent reduction in sediment for filtration practices using the median (Q2) observed value. PTMApp will use the percent reduction for each treatment group to “measure” load reductions (TP, TN, sediment and runoff) at the BMP and at the priority resource.

Table 2. Empirical Statistical distribution for sediment removal within the filtration treatment group and the resulting decay coefficient (*k*). Based on data from the MN Ag. BMP database.

Treatment Group	Min, %	Q1, %	Q2, %	Q3, %	Max, %	k
Filtration	0.44	0.54	0.75	0.91	1	0.74

Figure 3. Treatment decay functions based on reduction ratios for filtration practices.

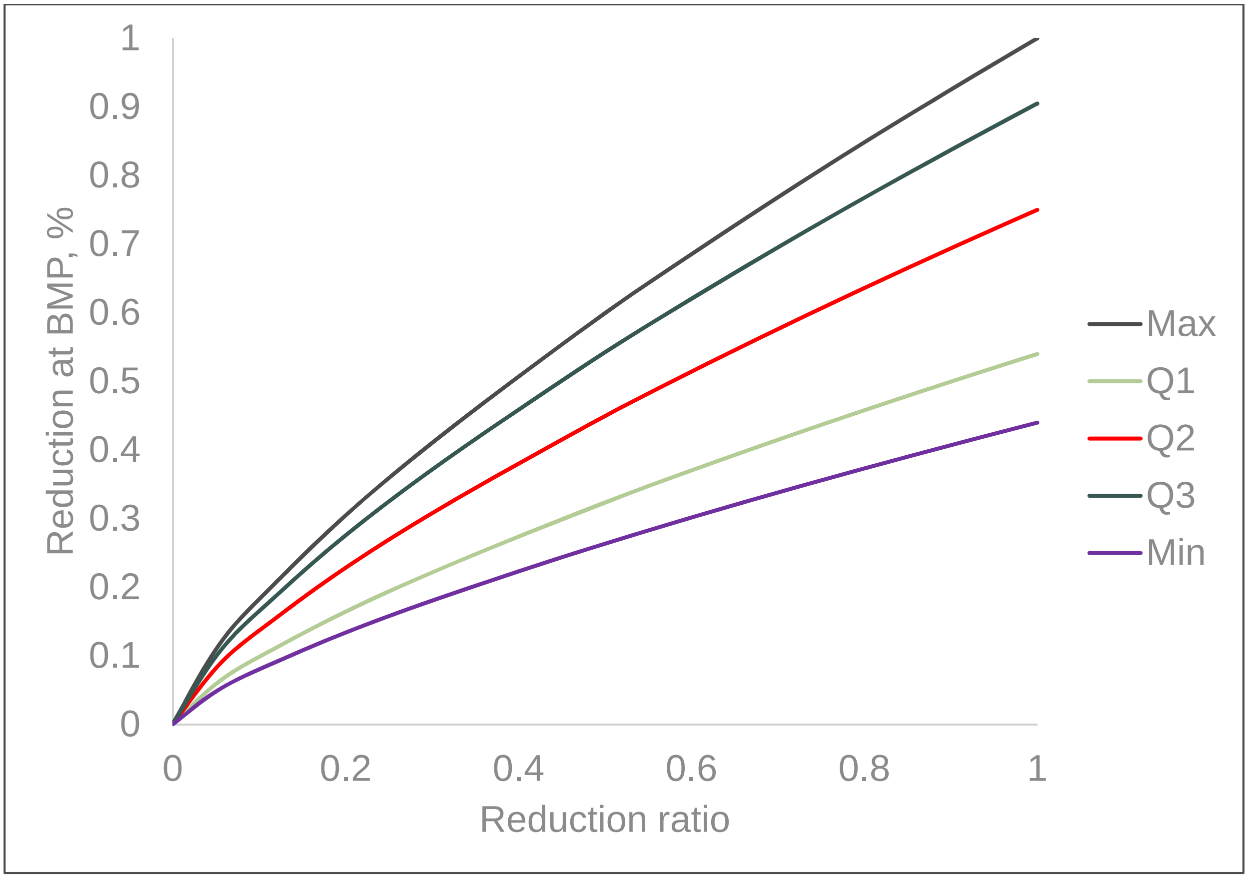
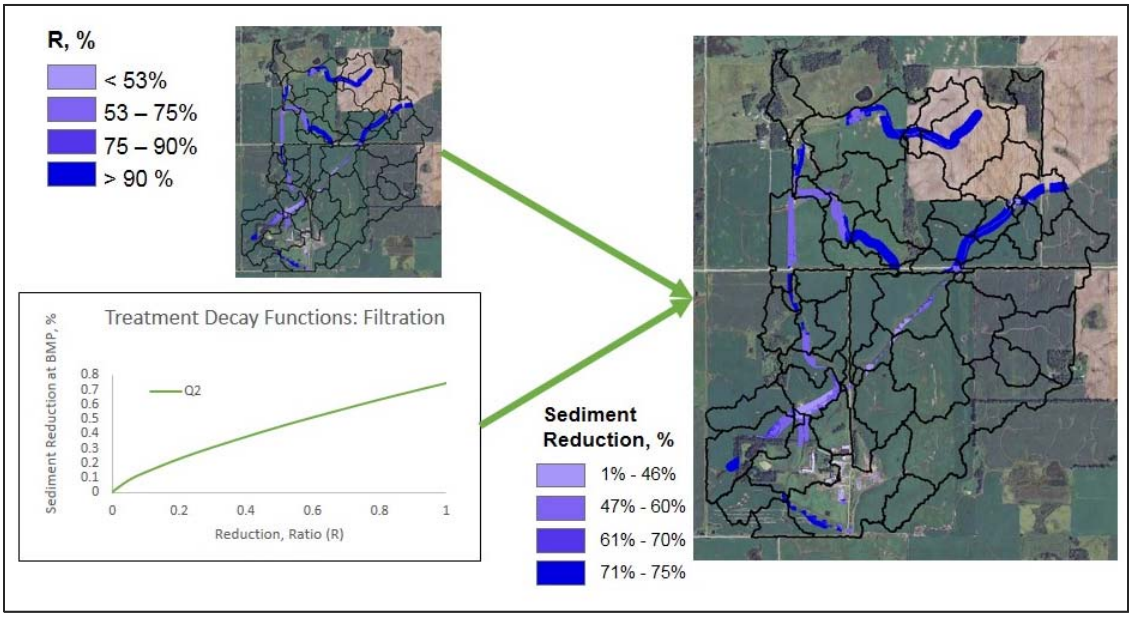


Figure 4. Conversion of the reduction ratio to a percent reduction in water constituent (sediment) using the treatment decay function for filtration practices.

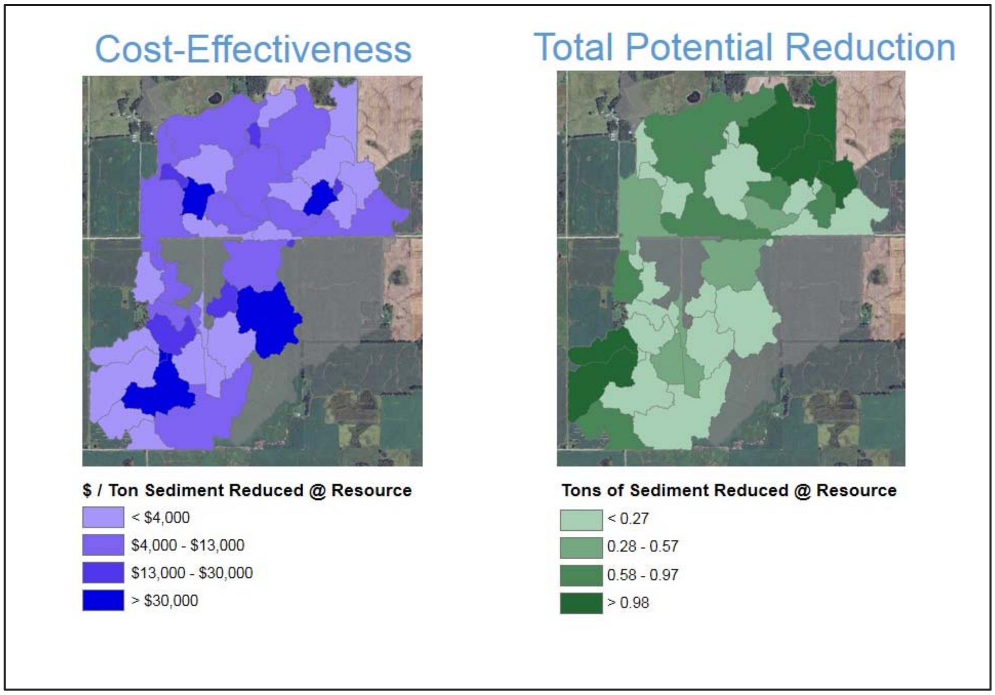


Estimating Cost-Effectiveness and Optimum Treatment

The IWI and HEI intend the estimate the potential cost associated with implementing BMPs and CPs on a per unit area, length or volume for each BMP treatment group as part of the PTMApp development. Each treatment group will have a default cost derived from best available information (e.g. MN Ag BMP Handbook, NRCS EQUIP payment schedules). End user's will also have the option to override the default cost value based on local experience. For this example, it was assumed that filtration practices could be implemented at $1,000 / acre.

The percent sediment reductions calculated above (see Figure 3) were applied to sediment loading estimates delivered to a downstream resource of concern (i.e. main stem of the Sand Hill River). The sediment loading estimates were calculated using the data and techniques develop as part of a 2012 Accelerated Implementation Grant (described above). The sediment load delivered to the Sand Hill River was then scaled based upon the Hydrologic Simulation Program-Fortran (HSPF) model for the Sand Hill River watershed (meaning loads were adjusted from the terrain analysis products to match the calibrated HSPF modeled loads). We intend to allow users to scale loading data provided within the PTMApp based on existing models and/or gage (observed) data or other external knowledge. Figure 5 shows the resulting cost-effectiveness ($ / Ton of sediment reduced at the Sand Hill River impaired water) and total potential sediment reduction by field scale catchment. This information could be used during the 1W1P process to identify areas with the most cost-effective and highest potential for treatment of issues (TP, TN, sediment and runoff) impacting priority resources. It could also be used to inform measurable goals and establish implementation strategies.

Figure 5. Dollars per ton of sediment reduced at the Sand Hill River and Total potential sediment reduction at the Sand Hill River. Grey catchments lack opportunities for filtration practices.



The BMP cost-effectiveness was then used to identify single practice implementation efficiency frontiers (Figure 6). In other words, the efficiency frontier identifies the minimum measured dollar investment needed to achieve a given amount of reduction in water constituent (TN, TP, sediment, and runoff) at a priority resource. This output could serve to inform the potential efficiency (i.e. cost-effectiveness) of proposed implementation projects. Proposed projects that are close to the maximum possible efficiency should provide more cost-effective treatment relative to projects that are further away from the maximum possible efficiency.

Figure 6. Single treatment efficiency frontier for filtration practices. Frontier indicates the maximum reduction in sediment delivered to the main channel of the Sand Hill River relative to the implementation cost.

CONCLUSIONS

This TM has been provided to BWSR to facilitate review of the techniques proposed for measuring BMP effectiveness for inclusion in the PTMApp. IWI and HEI intend for the methods highlighted above to provide information and data products that can be utilized during 1W1P development to inform the analysis and prioritization of resources and issues impacting resources, setting measurable goals, and developing implementation strategies. Upon agreement on these methods, IWI and HEI will assume that the methods meet BWSR's requirements for prioritizing, targeting, and measuring as part of 1W1P development process.

These methods are open to discussion and subject to change based upon BWSRs requirements. Once finalized, the "measure" methods will be used for the development of the PTMApp. Future changes to the "measure" methods after initial establishment, could result in a need to adjust the overall project scope and timeline. We request that after review of this TM, BWSR submit any comments/preferences necessary to ensure that the "measure" methods are suitable for development of the PTMApp.

Acknowledgement

By initializing this TM I concur with the intended direction for application development.

12/2/14

Doug Thomas
Board of Soil and Water Resources

REFERENCES

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APPENDIX A. Hydrologic conditioning standards.

Minimum Criteria		DEM Reconditioning and Data Product Scale				
		Fine			*Coarse*	
		A	B	C	D	E
1	**Elevation Source Data**	High Resolution Topographic Data (e.g., using LiDAR)				USGS National Elevation Dataset
2	**Mininum drainage area threshold used for Quality Control**	< 1 sq. mile	1 - 5 sq. miles	5 - 10 sq. miles	> 10 sq. miles	All Ranges
3	**Maximum Digital Elevation Model and Raster Data Product Resolution**	5 meter	5 meter	10 meter	30 meter	Any
4	**Hydrologic Boundary and Vector Data Product Resolution**	160 acres maximum *(Ideally 40 acres)*	1 square mile maximum	5-10 sq. mile maximum	> 10 square mile maximum	12-digit HUC
5	**Source of Reconditioning Data**	User intrepretation using source elevation data, supplemented with field-verified data where required	User intrepretation using source elevation data, supplemented with field-verified data where required	User intrepretation	User intrepretation	Existing GIS dataset (NHD, MnDNR 24k Streams, etc...)
6	**Intensity of Recondition**	High *Several iterations by experienced hydrologist to meet Criteria 2*	Moderately High *Several iterations by experienced hydrologist to meet Criteria 2*	Moderate *Minimal iterations by experienced hydrologist to meet Criteria 2*	Low *Minimal iterations by experienced hydrologist to meet Criteria 2*	None
7	**Data Products and Functionality**	BMP Design Water Quality Overland Flow On-the-fly Watershed Delineation Hydrographics Gridded Parameter Modeling "Lumped" Parameter Modeling	On-the-fly Watershed Delineation Hydrographics "Lumped" Parameter Modeling	Hydrographics "Lumped" Parameter Modeling	Hydrographics "Lumped" Parameter Modeling	NHD Plus

"User interpretation" implies photographic interpretation combined with the source elevation data to make assumptions on drainage characteristics.